Title: Intro to Fuel Cells

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Subject: Regents Chemistry
Level: High School
Standards: NYS Chemistry Core Curriculum 3.2d-h, i-l
Schedule: 40 minute period

Objectives:

-Students will understand the various parts of electrolytic cells
-Students will be able to assign oxidation numbers to various elements within different redox equations
-Students will have an appreciation for the technology of fuel cells.

Students will:

- Be able to identify various parts of electrolytic cells on a diagram
- Differentiate between voltaic cells and galvanic cells
- Write out the equation of oxidation numbers for hydrolysis
- Understand reversible reactions
- Identify the components of a hydrogen fuel cell
- Have an appreciation for hydrogen fuel cells as an alternative to carbon-based fuels.

Vocabulary:

Materials:

Hoffman Apparatus (or other electrolysis set-up)

Fuel Cell*

Worksheets for students

Voltmeter

Small motorized fan*

*See "Preparation"

Science Content for the Teacher:

In recent years, the search for alternative energy sources has moved from an academic curiosity to an economic necessity. The twin pressures of rising oil prices and long-term climate change have necessitated a shift away from a carbon-based fuel economy. Scientists, engineers, and corporations are hard at work exploring various alternatives. One choice is to move toward a hydrogen-based economy where transportation no longer relies on the internal combustion engine, but on a hydrogen fuel cell.

A 150 year-old technology, hydrogen fuels cells are attractive alternatives for a number of reasons. One reason is efficiency. An internal combustion engine is limited by Carnot Efficiency, while a fuel cell converts chemical energy *directly* to electrical energy. Hydrogen fuel cells have the added benefit of producing nothing but water. This is a very appealing idea in our carbon-conscious age.

The purpose of this activity is to introduce students to this technology and also make a connection to the oxidation and reduction portion of the New York State chemistry curriculum. Students will become familiar with the basic idea behind hydrogen fuels cells and comparisons with voltaic fuel cells will also be made. Instructors may wish to also discuss the history of the cell, potential future applications, and the potential of hydrogen as a fuel source of the future. This activity is meant to spark real-world interest in both energy and electrochemical cells, both of which will be prevalent and changing technologies in the 21st Century.

For this lesson students should already be studying oxidation and reduction and should be familiar with these terms as well as voltaic cells.

For more information see the "supplemental sources" listed below.

Preparation:

You will need to use a Hoffman apparatus or some other electrolysis set-up for this demonstration. Your set-up must contain an outlet for the controlled release of hydrogen (and perhaps the oxygen); preferably something that allows for tubing to be attached. A diagram of such an apparatus is shown in **Figure 1** below.

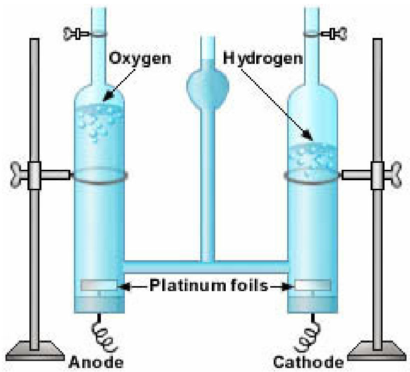

Figure 1: A Hoffman Apparatus traditionally used for hydrolysis demonstrations.
www.answers.com

You will also need a fuel cell for the demonstration. A "Master Fuel Cell" purchased from the website www.fuelcellstore.com was used during the testing of this demonstration. While the price may be a drawback, it was found to be quite efficient. There are examples in the chemical education literature of a glass apparatus that can be made, however this may not be practical. You will also need some plastic tubing of appropriate diameter to connect your electrolysis experiment with the fuel cell. Finally, you will need a small electronic device to attach to the fuel cell to demonstrate the creation of electricity. A suggestion is the small fan provided by the website above or light emitting diode requiring a voltage of less than 0.8V (the fuel cell will not support anything greater).

Remember that an electrochemical cell requires the transfer of charge and that distilled or even tap water is probably inadequate. It is recommended that sodium bicarbonate is added to the solution in order for the reaction to occur at a desired rate.

Classroom Procedure:

This lesson will take anywhere from **40-50** minutes.

Engage (Time: 8-10 minutes)

Students should walk into class and see the electrolysis demonstration set-up. The teacher may want to use a flex-cam or other camera connected to a television to ensure visibility for smaller set-ups. The instructor should introduce the idea of separating water into its component elements and then perform the demonstration. By now, students should have an understanding of what oxidation and reduction are and should be able to write the basic equation for the hydrolysis of water. Have students take a minute and write out the equation, making sure to properly balancing the equation. Next have students write the oxidation numbers for hydrogen and oxygen on BOTH sides of the equation. Have them identify what is being oxidized and what is being reduced from left to right.

Now, unplug the DC power supply and connect the fuel cell as discussed above. Do not tell students what the fuel cell is. Now connect the small fan to the fuel cell. Make sure students can see that NO PART of the set-up is connected to the wall (maybe even have a student come up to double check). Finally, release some hydrogen from the tube it is stored in. Your fan will begin to run instantly. Ask students to hypothesize how the fan is capable of running while disconnected from the wall. After a few minutes (depending on how much hydrogen was produced) the fan will stop. Ask students why it stopped.

Explore (Time:* 8-12 minutes*)

Hopefully there will be students who will be able to figure out that it has something to do with the gases, however the fuel cell is still a "black box". The objective now is to be able to for **students towards an understanding of what is taking place within the fuel cell** based on both their previous knowledge and the first demonstration:

Helpful questions might include:
-"Where *could* the electrical energy is coming from? Where else have we seen electricity created?" Students should hopefully make a connection between what their seeing and galvanic cells, a topic that should have been introduced before this period. Electrical energy is coming from stored chemical energy in the form of hydrogen and oxygen.

-“What is happening to the hydrogen within the fuel cell?” or “Describe the reaction taking place with the hydrogen”

-What might it be reacting with? What might it be producing? What does hydrogen have to do with electricity?

-“If hydrogen is reacting, why do we not see a flame or hear it’s characteristic ‘bark’?”

-“What is electricity/current? Where are these electrons coming from?” Students may already know, or need to be introduced to the definition of current, essentially moving electrons.

-“Where are these electrons traveling to?” [Oxygen]

-“What type of ions do hydrogen and oxygen tend to become?”

Based on the answers to these questions, have students either draw a diagram or write a description of what they think is happening within the fuel cell.

Explain (Time:** 8-12 minutes**)

This time should be devoted to discussion of what a fuel cell is and the process of oxidation and reduction that is occurring within. History of the fuel cell and potential commercial applications should be addressed as well. Please see the *Supplement* section below.

At this point students should compare their diagram of a fuel cell with the accepted diagram.

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Expand (Time: 5-10 minutes)

Discuss and calculate (as a class) the efficiency of a hydrogen fuel cell versus the internal combustion engine. Most chemistry students are in their junior year and have driving on the brain. Such a discussion is a real-world connection to the material.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term "expectations" here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

1= exceeds expectations
2= meets expectations consistently
3= meets expectations occasionally
4= not meeting expectations

	Engage	Explore	Explain	Expand/Synthesis
1	Student contributes to class discussion using previous ideas.	Student shares at least 1 idea with the class.	Student fully completes note sheet.	Students complete math problems in class.
2	------------------	Student contributes 2 ideas.	Students partially complete sheet.	----------------------
3	------------------	Student contributes 1 idea.	Student answers less than half of note sheet.	----------------------
4	Student gives no contribution to class discussion.	Student makes no contribution to group discussion.	Note sheet is blank.	Student gives no contribution to class discussion.

Extension Activities:

-Discussion of using renewable energy sources, such as solar and wind, to produce hydrogen via electrolysis.
-Fuel Cell applications for homes and offices.
-Make your own fuel cells.
- A discussion of the positive and negative aspects of replacing our carbon-based economy with a hydrogen-based one.
-History of the Fuel Cell
-Other types of fuel cells (ie: methanol)

Supplemental Information:

Young, G.J,; Rozelle, R.B. "Fuel Cells" *Journal of Chemical Education.* 1959, 36, 68.

Roffia, S., et al. *Journal of Chemical Education.* 1988,65, 725.

Cornell Fuel Cell Institute: http://cfci.ccmr.cornell.edu

"Fuel Cell Basics" http://americanhistory.si.edu/fuelcells/basics.htm#q2

"Lovin' Hydrogen" *Discover* Magazine. November 1st, 2001.

Safety:

PLEASE REMEMBER! Hydrogen gas is extremely flammable. This demonstration should not take place near any open flames.

Also, if using an AC adapter for a DC power source, please be careful while conducting the electrolysis portion of this lesson.

Acknowledgments:

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Name ________________________

"Introduction to Fuel Cells" Class Activity

<u>Demonstration 1</u>: Hydrolysis

An **electrochemical cell** is a system in which chemical energy is converted to electrical energy. You have already learned that **voltaic** cells produce electricity via oxidation and reduction. These cells are often linked together to form the many batteries we use everyday, such as the one in your cell phone. But what happens when your cell phone battery stops doing its job (letting you talk to your friends)? You recharge it of course! But why do you plug it into the wall?

<u>Electrolytic cell</u>:

<u>Hydrolysis</u>:

<u>Hydrolysis set-up</u>:

Write the balanced chemical equation for the hydrolysis of water into hydrogen and oxygen. For each compound be sure to write the oxidation state of each element.

At which electrode is hydrogen being produced? How do you know?

At which electrode is oxygen being produced? How do you know?

Demonstration 2:

After observing the fan in operation, make one hypothesis as to what is going on:

After observing the fan stop operating, make one hypothesis as to why it stopped:

Draw or explain in words, what is going on within the fuel cell:

Below, compare your fuel cell with the diagram used in class. What is similar and what is different?

Part 3: Additional Questions

1. Give 1 similarity and 1 difference between voltaic cells and fuel cells.

2. The maximum theoretical voltage that can be produced from one hydrogen fuel cell is 1.23 volts. What special importance do you think this number plays in the electrolysis of water?

3. One of the major benefits of a fuel cell is that its efficiency is much greater than that of the internal combustion engine, due to the limits of Carnot efficency. The best contemporary car engines work at 30% efficiency. Calculate the efficiency of a fuel cell below. Assume 30ml of H_2 were used to keep the fan moving at full speed for 45 seconds.

    a. What is the theoretical energy, in Joules, of a 30mL sample of H_2 gas?

    b. In order to find energy efficency, you must know the current (in amperes) that was traveling though the fan. If one amp equals 1 Coulomb/second, what was the current? (1 mol of electrons is 9.65×10^4C).

    c. Energy Efficiency = $\frac{volt * current * time}{theoretical}$ * 100%. The maximum practical voltage of a hydrogen fuel cell is 0.8 volts. Calculate the efficiency.

4. One of the potential uses for hydrogen fuels cells is as a replacement of lithium ion batteries for long durations of time when electricity is unavailable. The average laptop battery in 2004 would run 5 hours and would have an energy of 25,200 Joules. Assuming that the battery was at 3.75 volts,

   a. How many moles of electrons is this? $\text{volts} = \dfrac{Joules}{Coulomb}$

      Again remember that 1 mole of electrons = 9.65×10^4 C.

   b. How many moles of hydrogen would be needed to replace the battery?

   c. What volume of hydrogen would correspond to the answer for part B?